Clogging of Porous Pavements
- International Experiences

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- International Experiences

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## Contents

Preface .......................................................................................................................... 5  
Forord ........................................................................................................................ .. 6  
Summary ...................................................................................................................... 7  
Sammenfatning ............................................................................................................ 9  
1. Introduction ....................................................................................................... 11  
2. Method ............................................................................................................... 12  
3. Literature about Clogging .............................................................................. 14  
   3.1 Clogging of porous asphalt ........................................................................ 16  
   3.2 Design of less clogging porous asphalts ................................................... 17  
   3.3 Cleaning methods for porous asphalt ......................................................... 19  
   3.4 Environmental effect of using porous asphalt (water) .............................. 22  
4. Conclusion ....................................................................................................... 24  
5. References ....................................................................................................... 26
In early 2004, the Danish Road Institute/Road Directorate (DRI) and Road and Hydraulic Engineering Institute in the Netherlands (DWW) signed an agreement to cooperate on the DRI-DWW Noise Abatement Programme in the period 2004 to 2007 [25]. A total of 7 research and development projects will be carried out within the framework of this program. The DRI-DWW noise abatement programme is a part of the Dutch IPG program on development and testing of noise reducing measures for road traffic [24].

One of these projects is the Clogging of Porous Pavements Project [25] and the main objective of the joint project is to develop, describe and suggest possible ways in which to maintain the noise reduction of two-layer porous pavements over the whole structural lifetime of the pavements by avoiding clogging.

This literature study was prepared in 2005. The study is Milestone M3 of the Clogging of Porous Pavements Project. The study has been produced by a DRI working group with the following members:

- Hans Bendtsen (DRI project leader).
- Jørn Raaberg.

Et af disse projekter er "Tilstopning af drænasfalt" [25] og hovedformålet med dette fælles projekt er at udvikle, beskrive og foreslå muligheder til at vedligeholde den støjreduktion som opnås ved brug at 2-lags drænasfalt igennem hele dens strukturelle livstid ved at undgå tilstopning.

Dette litteraturstudie er udarbejdet i 2005. Det er Milestone M3 i projektet "Tilstopning af drænasfalt" Rapporten er skrevet af en VI arbejdsgruppe bestående af:

- Hans Bendtsen (DRI projekt leder).
- Jørn Raaberg.
Summary

The advantage of porous pavement types is that they have a low noise emission and have a low amount of splash and spray. Both aspects tend to deteriorate during lifetime. One important reason for this is clogging of the pores. The deterioration of the noise reduction and the drain ability is unwanted and should be kept to a minimum. This report deals with the existing knowledge and methods to achieve this. A world wide literature review has been performed and a scan tour to Japan was organized to get information about the latest developments on the clogging in Japan. The experiences from the tour to Japan are reported in a separate report.

It has been agreed on that Dutch experiences are not included in this report as they will be dealt with by DWW in another part of the clogging project. Generally not very much international literature concerning clogging has been retrieved, indicating that world wide this specific issue has not been a big theme for research.

In the international literature, many references have been found which mention clogging. Most of the references only use the word and do not go into a special description of what the materials that causes the clogging consist of or where in the porous pavement the clogging is located. There are some different opinions on where in the pavement layer the clogging begins. The general opinion in most of the literature is that clogging occurs in the top of the pavement and this is highlighted by Danish analyses of thin and plane sections of drill cores where the clogging material can be seen in the porous.

The clogging is due to solid particles and liquid originating from both traffic and the surroundings of the road. Some literature describes it as dust, sand, rubber (tire), oil etc. The materials that formed the clogging contain heavy metals and the water used for cleaning the pavements must be treated in a way that takes care of the environment.

Even though surfaces paved with porous asphalt do not receive traffic the open structures clog due to dust and sand.

To avoid the clogging all papers agree in that higher speed for the vehicles and more traffic passing over the pavement the less clogging are seen. Also concerning the design of the porous pavement most of the papers can agree on that the higher air voids content the less clogging. This will of course have an influence on the lifetime of the pavement in an undesirable way because the bitumen is hardened due to oxidation, but the use of polymer modified bitumen can be seen as a factor to avoid this. Danish experiences indicates, at least for urban roads with lower speeds that the maximum aggregate size must not be too small in order to avoid or reduce the tendencies for clogging. Less tendencies of clogging was in this long time experiment seen at two layer porous pavements with 8 mm maximum size in relation to pavements with 5 mm aggregate.
By designing the porous asphalt in the right manner, it would be possible to get a pavement which clogs less:

- The air void content has to be between 25 to 30 % which has been stated in several of the papers.
- The maximum size of aggregate used must not be too small (around maybe 8 mm).
- The shape of the aggregates should be taken into account. Cubic aggregate are favourable.

One way to retain the permeability of porous asphalt is to clean the surface. Different equipments have been developed to do this. The principle most of these are based upon are spraying water through nozzles and immediately after vacuum cleaning water and dirt from the surface. In Germany a research team has started working on using polymer-nanotechnology to making the asphalt less sticky to “dirt” in order to reduce clogging.

According to the results of the literature study the recommendations for reducing the tendencies of clogging for porous pavements are:

- To secure a high air voids content.
- To use not too small maximum aggregate size.
- To use cubic aggregate.
- To secure that the geometric characteristics of the road should be correct so that rain water can run to the road side.
- To perform cleaning on urban roads with porous pavements.
- Perform cleaning after a period with rain as this might soften up the clogging material.

But from the literature study it is also quite clear that further research into the clogging phenomenon and optimized cleaning processes is needed in order to improve the noise reducing effect of porous pavements.
Sammenfatning


I den internationale litteratur er fundet en del artikler, som nævner tilstopningsproblemet. De fleste af disse referencer nøjes med at gøre opmærksom på problematikken, men går ikke ind i en mere detaljeret beskrivelse af problemet. F.eks. hvilke kilder der bidrager til tilstopningen, og hvor i belægningen tilstopningen findes.

I gennemgangen af de fundne referencer bemærkes, at der er forskellige holdninger til, hvor i drænasfalten tilstopningen starter. Den generelle holdning i de fleste artikler er, at tilstopningen foregår i overfladen af belægningen, hvilket tillige er eftervist af danske undersøgelser ved hjælp af plan- og tyndslib på udtagene borekerner med tydeligt indhold af tilstopningsmateriale i porerne.

Tilstopningen forårsages af materiale fra trafikken og fra vejens omgivelser. Nogle artikler beskriver dette materiale som støv, sand, dækrester, olie, etc. Materialet indeholder tungmetaller, og i det tilfælde belægningen rengøres ved vandspuling må det anvendte vand håndteres i henhold til gældende miljøkrav.

Trafikkens påvirkning er meget markant, og i litteraturen er da også enighed om, at trafikkens hastighed og intensitet har stor betydning, idet såvel højere hastighed som større trafikmængde reducerer tendensen til tilstopningen. Ligeledes har drænasfaltens hulrum stor betydning, og i hovedparten af litteraturen peges på, at et højt hulrum mindsker tilstopningen. Et højt hulrum har dog en ønsket effekt på belægningens levetid, da luftens adgang til poresystemet øger ældningen af bindemidlet. Anvendelse af polymer modificeret bitumen har dog vist sig fordelagtig i forhold til ældningsprocessen.
På veje i byer med lav hastighed har danske erfaringer vist, at tilslagets kornstørrelse ikke må være for lille af hensyn til tendensen til tilstopning. Således er der over en længere periode observeret en mindre tilstopning i en to-lags drænasfalt med en 8 mm maksimum kornstørrelse sammenlignet med en tilsvarende opbygning med en 5 mm maksimum kornstørrelse.

I det tilfælde belægningen ikke trafikeres vil tilstopningen ligeledes finde sted, da drænasfaltens åbne struktur også i dette tilfælde tilstopper med sand og stov.

Ved design af en drænasfaltbelægning er det vigtigt, at hensynet til tilstopning håndteres på den mest optimale måde for at opnå en belægning med mindst mulig tendens til tilstopning:

- Hulrummet skal være mellem 25 til 30 %, hvilket er beskrevet i en stor del af litteraturen.
- Tilslagets maximale kornstørrelse må ikke være for lille (Bør være 8 mm).
- Stenmaterialets kornform har betydning. Kubiske sten er at foretrække.

En måde at genskabe permeabiliteten i en drænasfaltbelægning består i en vandspuling af belægningsoverfalden. Forskellige former for materiel er udviklet til dette formål. Rensningen foregår på den måde, at belægningsoverfladen vandspules fra en spredetramme på tværs af kørebanen og i samme proces opsuges vand og snavs fra overfladen.

Med det formål at reducere drænasfaltens tendens til tilstopning har et tysk forskerhold indledt et arbejde med polymernanoteknologi for at reducere asfaltmaterialets tendens til at binde stovpartikler.

Gennemgangen af litteraturen gav følgende anbefalinger i forhold til at reducere en drænasfaltbelægnings tendens til at tilstoppes:

- Sikre et højt hulrum i den indbyggede belægning.
- Ikke at anvende for lille maksikornstørrelse af tilslaget.
- Anvende cubiske stenmaterialer.
- Sikre at vejens profil er tilstrækkelig for korrekt vandafledning.
- Udfør rensning af veje i byer med langsom trafik.
- Udfør rensning efter en periode med regn, fordi nedbøren “opløser” snavset i drænasfaltens porer.

Den udførte litteraturgennemgang har vist, at der er behov for yderligere forskning i mekanismerne for tilstopning af drænasfalt samt i metoder for rensning. Dette af hensyn til forbedringer af den støjreducerende effekt af drænasfaltbelægninger.
1. Introduction

The main objective of the project on Clogging of Porous Pavements of the DRI-DWW noise abatement programme is to develop, describe and suggest possible ways in which to maintain the noise reduction of two-layer porous pavements over the whole structural lifetime of the pavements by avoiding clogging. The purpose with this literature study is to find and systemize the existing knowledge outside the Netherlands of both clogging and cleaning of porous asphalts, so this can form a basis for further new developments. It has been agreed on that Dutch experiences are not included in this report as they will be dealt with by DWW in another part of the clogging project. Also scan tour to Japan was organized in November 2005 to get information about the latest developments on the clogging in Japan. The experiences from the tour to Japan are reported in [26].

Figure 1.1. Equipment to measure permeability on porous pavements.
2. Method

Systematic literature searches have been carried out by the DRI research library in order to find references that could provide relevant information that could help to answer the research themes listed below. Amongst others, the ITRD database has been used. DWW has also contributed with relevant references. The following key words have been used for the searches:

- Porous pavement and clogging.
- Cleaning and two-layer porous pavement.
- Permeability and porous pavement.
- Permeability and measurement.
- Noise, porous pavement and clogging.

Relevant papers have also been found in the proceedings from conferences that DRI researchers have participated in during the last five to ten year period. This covers conferences in road technology such as:

- The annual Transportation Research Board meetings (TRB).
- The Euroasphalt & Eurobitumen congress in Vienna in 2004.
- The Ninth International Conference on Asphalt Pavements (ISAP) in Copenhagen in 2002.

The subjects are organised in the follow research themes:

- Clogging of porous asphalt.
- Design of less clogging porous asphalts.
- Cleaning methods for porous asphalt.
- Environmental effect of using porous asphalt (water).

Each reference is classified according to these subjects being relevant to one or several subjects. After this initial classification, each subject is assessed in separate paragraphs summarising all experiences within this subject. In a final assessment of the international experiences some knowledge gaps are identified.

It is the intention to keep the present note as brief as possible, only including the most relevant statements from literature which are of interest for the final assessment. It should also be noted that only selected references referred to in the present note are included in the reference list. This selection is made from a broader assessment of international literature. With the exception of one Norwegian paper, only references in English language are included, since these are easily accessible to most people, but other selected references have been scanned.
The reference lists in the selected references have been scanned, but references only included if the subject was not covered by a newer reference. The reference list is sorted in alphabetic order by the first author and referred to with a number in square brackets according to this order.
The search for literature on the subjects of clogging and cleaning of porous asphalt results in the listed papers in Table 3.1 (part 1 and 2).

Table 3.1 (part 1). The literature retrieved covering different aspects of clogging, cleaning and mix design in relation to porous asphalts.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Institution</th>
<th>Year of publication</th>
<th>Title</th>
<th>Research questions included</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tan S.A., Fwa T.F. and Guwe Y.K.</td>
<td>University of Singapore</td>
<td>2000</td>
<td>Laboratory measurements and analysis of clogging mechanism of porous asphalt mixes [2]</td>
<td>Laboratory test and setting up a model for the clogging process</td>
</tr>
<tr>
<td>Lane R.</td>
<td>Pavement Treatment Ltd.</td>
<td>2005</td>
<td>Cleaning open graded asphalt to improve safety [3]</td>
<td>Describes test with cleaning of porous asphalt</td>
</tr>
<tr>
<td>Tan S.A., Fwa T.F. and Chai K.C.</td>
<td>University of Singapore</td>
<td>2003</td>
<td>Drainage consideration for porous asphalt surface course design [4]</td>
<td>The of the geometric design of the road on drainage capacity</td>
</tr>
<tr>
<td>Ranieri V</td>
<td>Polytechnic University of Bari</td>
<td>2002</td>
<td>Runoff control in porous pavements [5]</td>
<td>Gives a model for geometric design of the road to improve the drainage capacity</td>
</tr>
<tr>
<td>Lofthaug J.K.</td>
<td>ViaNova</td>
<td>1992</td>
<td>Støysvake vegdekkar [6]</td>
<td>Also here the influence of the design of the roads on the drainage is discussed</td>
</tr>
<tr>
<td>Michaut J.P.</td>
<td>Colas, France</td>
<td>1997</td>
<td>High void content porous asphalt [7]</td>
<td>Describes the increasing of the air voids to improve the permeability</td>
</tr>
<tr>
<td>Sainton A.,</td>
<td>Routiere Beugnet</td>
<td>1997</td>
<td>Four year evaluation of high voids content porous asphalt with HTV drainochape process [8]</td>
<td>Design of porous asphalt with up to 30 % of air voids</td>
</tr>
<tr>
<td>Raz R.T.</td>
<td>C.I.E.S.M. Spain</td>
<td>1997</td>
<td>Maintenance of permeability in porous mixes [9]</td>
<td>Also in this paper, the recommendation of using high air voids content to increase the permeability</td>
</tr>
</tbody>
</table>
Table 3.1 (part 2). The literature retrieved covering different aspects of clogging, cleaning and mix design in relation to porous asphalts.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Institution</th>
<th>Year of publication</th>
<th>Title</th>
<th>Research questions included</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bochove van G.G</td>
<td>Heijmans Road Construction Company B.V.</td>
<td>1996</td>
<td>Twinlay, a new concept of drainage asphalt concrete [11]</td>
<td>All these papers describe the development of two-layer porous asphalt and give recommendations on the cleaning process</td>
</tr>
<tr>
<td>Bochove van G.G</td>
<td>Heijmans Road Construction Company B.V.</td>
<td>1997</td>
<td>Two layered porous asphalt – A new concept civil technical properties and experiences [12]</td>
<td></td>
</tr>
<tr>
<td>Bochove van G.G</td>
<td>Heijmans Road Construction Company B.V.</td>
<td>2000</td>
<td>Porous asphalt (two-layered) – optimising and testing [13]</td>
<td></td>
</tr>
<tr>
<td>Battiato G., Donada M. and Grandesse P.</td>
<td>Autovie Road Research Center</td>
<td>1996</td>
<td>A new generation of porous asphalt pavements developed by Autovie Venete, DDL (Double Draining Layer) [14]</td>
<td></td>
</tr>
<tr>
<td>Battiato G</td>
<td>Autovie Road Research Center</td>
<td>1997</td>
<td>The recent Italian experience on porous asphalt. The “DDL pavement” [15]</td>
<td></td>
</tr>
<tr>
<td>Jansen R., van de Ven C.J.</td>
<td>Volker Stevin Materieel BV</td>
<td>1997</td>
<td>A new method for cleaning and removing porous asphalt [18]</td>
<td>Also this paper describes a new machine for cleaning porous asphalt</td>
</tr>
<tr>
<td>Legret M., Nicollet M., Miloda P., Colandini V., Raimbault G.</td>
<td>LCPC and Ecole Polytechnique Fedérale de Lausanne</td>
<td>1999</td>
<td>Simulation of heavy metal pollution from stormwater infiltration through a porous pavement with reservoir structure [21]</td>
<td>These papers deal with the environmental aspects of porous asphalt.</td>
</tr>
<tr>
<td>Colandini V., Legret M., Brosseau Y. and Balades J-D</td>
<td>LCPC and Laboratoire Régional des Ponts et Chaussées</td>
<td>1995</td>
<td>Metallic pollution in clogging materials of urban porous pavement [22]</td>
<td></td>
</tr>
<tr>
<td>Legret M., Colandini V.</td>
<td>LCPC</td>
<td>1999</td>
<td>Effects of porous pavement with reservoir structure on runoff water: Water quality and fate of heavy metal[23]</td>
<td></td>
</tr>
</tbody>
</table>
The advantage of porous pavement types is that they are very silent and have a low amount of splash and spray. Both aspects tend to deteriorate during lifetime. One important reason for this is clogging of the pores. The deterioration of the noise reduction and the drain ability is unwanted and should be kept to a minimum.

What is clogging? As described in [1] - an investigation of a porous asphalt residential driveway paved in 1990 near Macon, Georgia, USA - this is a black layer visible in the pavement pores about ½ inch below the surface. Obviously in this case, the mix design had not been carried out correctly, because the author’s hypothesis for clogging occurring on this driveway is that the binder has drainage of the aggregates in the top of the layer which together with organic dust clogged the air voids. Another effect of the binder drainage from the surface is the problem of ravelling; there is not enough binder in the top to keep the aggregate fixed to the surface.

### 3.1 Clogging of porous asphalt

In literature, there are many references to the words clogging and porous asphalt. Unfortunately most of these references only state the word and write that dust, tire rubber etc. forms a part of the clogging. Only few studies have been performed to investigate where and how the clogging occurs.

One of the most interesting papers is [2], where the authors describe some tests performed in the laboratory, where they try to simulate the clogging of air voids in porous asphalt. They used local soil as clogging materials. The test samples of porous asphalt have the dimension of 500 x 500 mm and different thicknesses of approximately 50, 75 and 100 mm. To measure the permeability, they used a falling-head permeameter, developed at the National University of Singapore. In their work, they tried to correlate the laboratory results obtained with a simple theoretical model which has been developed for the clogging of geotextiles, called Giroud's theory, and they found a fairly good relationship between the laboratory results and the theory. They mentioned that evaluation of the test results was complicated by the different air void ratios in the specimens and there was an obvious segregation of results according to the air voids contents.
In [3] the clogging materials are described as a build-up of detritus which from stereoscopic photography looks like cement. A further effect of the clogging which the author points out is the reduced skid resistance in rainy weather condition caused by oily material that accumulates in the voids and comes to the surface during rain. This effect is only described in this paper; and has not been observed by other researchers.

Some papers also mention or deal with the influence the geometric design of the road on drainage capacity, especially [4] and [5]. In [4] the authors describe a 3-dimensional finite element program which has been used to study the effects of the longitudinal profile and the cross fall. Using this program, it was proven that these parameters have a significant effect on the drainage capacity of porous asphalt.

The author of [5] have in this paper set out a model which gives a correlation between the hydraulic conductivity, the geometric characteristics of the road and the intensity of rainfall. This model has been tested in the laboratory and is based on the experimental data. A chart for the design of porous asphalt is presented. With this graph it should be possible to improve the porous asphalt design so surface runoff could be avoided.

In [6] which is a Norwegian report that deals with test sections of different age, the author has noticed that test sections which theoretically should be nearly the same, performed differently concerning quality and durability. The conclusion in the report is that the difference could be caused by different geometric characteristics and carriageway drainage. Another matter which the author also points out is the condition of the layer below the porous asphalt, when porous asphalt is paved on an old asphalt layer. The old layer should be performing well and the cross fall of it is essential, so it can lead the water away from the surface.

### 3.2 Design of less clogging porous asphalts

In the process of designing the porous asphalt, the possibility of obtaining a pavement that has a “resistance” to clog should be taken into consideration. Below is the advice found in literature to make a suitable design of porous asphalt.

Earlier experience made by a contracting company as mentioned in [7] has shown that the permeability decreases to only 50% in the first year, when porous asphalt has been used on heavily trafficked roads; however on roads with low traffic, the permeability has nearly disappeared. Therefore, the company has tried to develop porous asphalt, which can retain the permeability for a longer period. The company has increased the air void content to between 20 and 30%. This has resulted in an initial permeability of 2 cm/s where the level traditionally was 1.2 cm/s. The paper does not mention anything of the necessity of cleaning the pavements.

The same conclusion is given in [8], where the authors also deals with improving the permeability by increasing the air void content, in this case up to 30%. They have used binder with ground rubber from tire in this investigation.
In [9], which is a paper from Spain, recommendations are given on how to design and maintain the permeability. It is proposed to design the pavement with an air void content between 25 and 28%. The pavement had to be cleaned once a year, and in Spain it is recommended to do this just after the rainy season. The cleaning procedure must start within a year after paving. The author also advises to use this kind of pavement only in appropriate places and on suitable surfaces.

The experiences of UK are collected in [10]. Here the author describes the conflict which the road engineer meets. On the one hand, they have to ensure a long lifetime, but on the other hand they also have to give the porous layer the needed permeability. This means that the thick binder film must not drain from the surface of the aggregates during storage and transport. In the paper, the following advice is given to secure the permeability of the porous asphalt:

- The air void content should be greater than 20%.
- Aggregate should be greater than 11 mm and the shape should be cubic.
- The traffic speeds must not be low.
- No unpaved roads must lead the traffic up on porous asphalt.
- Sealing the surface of emergency lane on motorways.
- Cleaning the road.

The observation made by the author has been that the problem with clogging is less on areas which are trafficked than on areas which are not trafficked.

In the beginning of the 90’ies, the concept of using two-layer porous asphalt was started in the Netherlands. Papers [11, 12 and 13] describe the development in the Netherlands of these pavements. In these papers it is stated that clogging of the porous asphalt depends on a number of factors:

- The amount of dirt.
- The size and structure of voids.
- The cross slope of the underlying layer of dense asphalt concrete.
- The traffic speed and the cleaning effect of traffic.

Using the method called Hydrovac-method for cleaning, it has been possible to obtain nearly the same permeability as seen when the pavement was laid.

Also some test with two-layer porous asphalt has been performed in other countries and [14 and 15] refer to tests made in Italy. In these papers, two-layer porous asphalt has been designed to give a good drainage capacity and also to achieve better possibility to clean the pavement when it is considered necessary. One of the proposals is to make a requirement for the shape of the aggregates used in the top layer.
In Germany, nanotechnology will be developed for modified materials and used to improve porous pavements [16]. The idea is to change the properties of the modifiers used for adding to the bitumen to change the properties of the bitumen so it is able to react with water and by this help to avoid the dirt particles to glue to the bitumen and by this to avoid clogging.

3.3 Cleaning methods for porous asphalt
Throughout the years, many methods and equipments for cleaning roads and porous pavements have been developed. In most cases, the principle is based upon spraying water through nozzles and a vacuum-cleaning of the surface.

In [17] a new principle for a cleaning machine is described. The authors have through tests in the laboratory shown that by using a high speed water jet in static water they obtain better cleaning in a bigger area. Therefore, they developed a cleaning device where they apply the cavitation phenomenon (cavitation bubbles) whereby the bubbles generate high pressure on a large area as they collapse. In the field, it has been shown that the cleaning machine is able to recreate the original permeability of the porous pavements. Measuring of the permeability has been done by using an on-site permeability apparatus as recommended by the Japan Road Association.

The authors of [18] stated that the reason for clogging of the porous asphalt is the presence of a wet sludge formed in the bottom of the layer. This wet sludge consists of dust, sand, rubber (tire), oil etc. On the top of the pavement, in areas with no or low traffic, the open structure also decreases due to dust and sand. According to the authors, the cleaning procedure may have to be performed several times a year in the worst case. The cleaning machinery has to be designed, so that it is possible to ensure cleaning also in the bottom of the porous asphalt layer and the paper gives a description of a machine from the company “Volker Stevin Materieel” which should be able to clean in the bottom. The principle in the cleaning is placing a rubber plate on the surface and pressing water down into the pavement from the middle of the plate. The water will then be drawn off by suction around the plate.

Test for trying to clean the pavement with different water pressures (1000, 3000 and 5000 psi) in the cleaning process has also been carried out in [3]. From the result, the authors conclude that using 3000 psi gives the best result. Using 5000 psi causes loss of material from the pavement (ravelling) and 1000 psi does not improve the permeability. It has to be mentioned that thirteen sections were cleaned and that in some of the sections the permeability was improved more than in others. After the sections had been cleaned, chemical analyses of the water were carried out. These tests showed that the water contained copper, nickel, lead and zinc as well as an oily sludge.

In the project from Øster Søgade in Copenhagen Denmark [19] clogging and cleaning of an urban road paved with three different two-layer porous asphalt had been followed through 6 years. The cleaning had been performed twice per year and the permeability had been measured before and after the cleaning with high pressure water and sucking up of the sludge. Table 3.2 shows the construction of the three sections and the reference section.
Table 3.2. The two layer porous pavements on the Øster Søgade test section in Copenhagen [19]. (The size of the 5 mm aggregate is in reality 5.6 mm.).

<table>
<thead>
<tr>
<th>Pavement name</th>
<th>Type of asphalt</th>
<th>Total thickness</th>
<th>Top layer</th>
<th>Bottom layer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Thickness</td>
<td>Aggregate</td>
</tr>
<tr>
<td>PA8-70</td>
<td>Porous</td>
<td>70 mm</td>
<td>25 mm</td>
<td>5/8 mm</td>
</tr>
<tr>
<td>PA5-55</td>
<td>Porous</td>
<td>55 mm</td>
<td>20 mm</td>
<td>2/5 mm</td>
</tr>
<tr>
<td>PA5-90</td>
<td>Porous</td>
<td>90 mm</td>
<td>25 mm</td>
<td>2/5 mm</td>
</tr>
<tr>
<td>DAC8 (reference)</td>
<td>Dense</td>
<td>30 mm</td>
<td>30 mm</td>
<td>0/8 mm</td>
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In Figure 3.1 and 3.2 data from the measurements of permeability is presented measured by the Becker’s tube method. The unit on the Y-axes is the time it takes 10 cm of water to out through the porous structure meaning the lower the value the more permeable and open the porous pavement is. When the value goes up it is an indication for clogging. It can be seen that in some places (northbound lane) it has been possible to maintain a reasonable permeability over a long period. Especially the pavement with 8 mm maximum aggregate has a better performance than the two pavements with 5 mm aggregate but in the southbound lane permeability dropped very fast even though the lane had been cleaned.

Along the western side of Øster Søgade – next to the southbound lane – there is a gravel path and large chestnut trees, both of which may supply material which can clog the pores of the pavement. This may explain the poorer performance of the PA5 in the southbound lane, but in that case it is remarkable that it does not affect the PA8.

Another more reliable explanation may be that dust and dirt is brought onto the porous pavements from the reference pavement by the driving vehicles. This is confirmed by the fact that the clogging starts close to the dense reference pavement and builds up as time passes by down on the porous pavements in the driving direction. The reason that this phenomenon is not seen on the north bound lane is that before the test sections there are a 100 m long section with porous pavement. On this 100 m long section clogging has been building up (this has though only been registered by visual inspection). As mentioned the permeability has been measured about a week before and a week after the cleaning procedure. This is reflected by dots close to one another on the two figures. Generally there is not a remarkable decrease in flow out time just after the cleaning. So on a short term bases the cleaning do not improve the permeability, but it might prevent/reduce clogging over a longer period.
Figure 3.1. Measurements of permeability on the Øster Søgade test sections with the Becker’s tube method in left wheel tracks of the northbound lane [19, 20].

Figure 3.2. Measurements of permeability on the Øster Søgade test sections with the Becker’s tube method in left wheel tracks of the southbound lane [19, 20].
In 1999, 2000, 2004 and 2005 cores have been drilled in order to perform thin section analyses of the porous pavements on Øster Søgade. Materials which clog the pavement can not been seen in the thin section of the new pavement. The 4 years old pavement is more or less clogged in top layer. Clogging material is located in the top 20 mm of the top layer of the porous asphalt [20] where as there is no clogging in the bottom layer.

**3.4 Environmental effect of using porous asphalt (water)**

Both in laboratory investigation [21] and in field test [22 and 23] it has been shown that when water with contents of heavy metals (Pb, Cu, Cd and Zn) passes through pores, retention of the metals can be seen. The investigation reported in [22] shows that the concentration of heavy metals in the clogging material depends on the traffic intensity and also that the metals can be seen in all fractions of particles, but the highest concentration is seen in particles smaller than 40 µm. The study also indicates that the concentrations of metals are lower in porous pavement used for reservoir structures.
Figure 3.4. High pressure cleaning equipment on the Øster Søgade test sections with two layer porous asphalt in Copenhagen, Denmark.
4. Conclusion

In the international literature, many references have been found which mention clogging. Generally Dutch literature has not been included in this study. Most of the references only use the word and do not go into a special description of what the materials that causes the clogging consist of or where in the porous pavement it is located. There are some different opinions on where in the pavement layer the clogging begins. The general opinion in most of the literature is that clogging occurs in the top of the pavement and this is highlighted by Danish analyses of thin and plane sections of drill cores where the clogging material can be seen in the porous.

The clogging is due to solid particles and liquid originating from both traffic and the surroundings of the road. Some literature describes it as dust, sand, rubber (tire), oil etc. The materials that formed the clogging contain heavy metals and the water used for cleaning the pavements must be treated in a way that takes care of the environment. Even though surfaces paved with porous asphalt do not receive traffic the open structures clog due to dust and sand.

To avoid the clogging all papers agree in that higher speed for the vehicles and more traffic passing over the pavement the less clogging are seen. Also concerning the design of the porous pavement most of the papers can agree on that the higher air voids content the less clogging. This will of course have an influence on the lifetime of the pavement in an undesirable way because the bitumen is hardened due to oxidation, but the use of polymer modified bitumen can be seen as a factor to avoid this. Danish experiences indicates, at least for urban roads with lower speeds that the maximum aggregate size must not be too small in order to avoid or reduce the tendencies for clogging. Less tendencies of clogging was in this long time experiment seen at two layer porous pavements with 8 mm maximum size in relation to pavements with 5 mm aggregate.

By designing the porous asphalt in the right manner, it would be possible to get a pavement which clogs less:

- The air void content has to be between 25 to 30 % which has been stated in several of the papers.
- The maximum size of aggregate used must not be too small (around maybe 8 mm).
- The shape of the aggregates should be taken into account. Cubic aggregate are favourable.

One way to retain the permeability of porous asphalt is to clean the surface. Different equipments have been developed to do this. The principle most of these are based upon are spraying water through nozzles and immediately after vacuum cleaning water and dirt from the surface. In Germany a research team has started working on using polymer-nanotechnology to making the asphalt less sticky to “dirt” in order to reduce clogging.
According to the results of the literature study the recommendations for reducing the
tendencies of clogging for porous pavements are:

- To secure a high air voids content.
- To use not too small maximum aggregate size.
- To use cubic aggregate.
- To secure that the geometric characteristics of the road should be correct so that
  rain water can run to the road side.
- To perform cleaning on urban roads with porous pavements.
- Perform cleaning after a period with rain as this might soften up the clogging
  material.

But from the literature study it is also quite clear that further research into the clogging
phenomenon and optimized cleaning processes is needed in order to improve the noise
reducing effect of porous pavements.
5. References


<table>
<thead>
<tr>
<th>Nr./No.</th>
<th>Titel/Title/Shortcut</th>
<th>Forfatter/Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>29/05</td>
<td>International Experiences with Thin Layer Pavements</td>
<td>Hans Bendtsen, Jørn Raaberg, Sigurd N. Thomsen</td>
</tr>
<tr>
<td>30/05</td>
<td>Traffic noise at two-layer asphalt – Øster Søgade Year no. 6</td>
<td>Jørgen Kragh</td>
</tr>
<tr>
<td>31/05</td>
<td>Noise reducing pavements in Japan - study tour report</td>
<td>Hans Bendtsen, Carsten Bredahl Nielsen, Bent Andersen, H.J. Ertman Larsen</td>
</tr>
<tr>
<td>32/05</td>
<td>Workshop on Optimization of Noise Reducing Pavements</td>
<td>Hans Bendtsen, Helen Hasz-Singh, Carsten Bredahl Nielsen</td>
</tr>
<tr>
<td>33/05</td>
<td>Friktion og MPD-tal</td>
<td>Bjarne Schmidt, Birger Roland Jensen</td>
</tr>
<tr>
<td>34/05</td>
<td>Trafikstøjmåling Tesdorpsvej – September 2005</td>
<td>Sigurd N. Thomsen, Bent Andersen, Jørgen Kragh</td>
</tr>
<tr>
<td>35/06</td>
<td>Test of thin layers on highway - Year 1 measurement report</td>
<td>Sigurd N. Thomsen, Hans Bendtsen, Jørgen Kragh</td>
</tr>
<tr>
<td>36/06</td>
<td>Noise reducing thin layers - Promising concepts</td>
<td>Hans Bendtsen, Erik Nielsen</td>
</tr>
<tr>
<td>37/06</td>
<td>Seminar on road noise abatement</td>
<td>Hans Bendtsen, Carsten Bredahl Nielsen, Helen Hasz Singh</td>
</tr>
<tr>
<td>38/06</td>
<td>Acoustical characteristics of Danish road surfaces</td>
<td>Jørgen Kragh</td>
</tr>
<tr>
<td>39/06</td>
<td>Noise reducing SMA pavements – Mix design for Silence – F2</td>
<td>Erik Nielsen, Jørn Raaberg, Hans Bendtsen</td>
</tr>
<tr>
<td>40/06</td>
<td>Ravelling of porous asphalt - Seletion of road sections</td>
<td>Carsten Bredahl Nielsen</td>
</tr>
<tr>
<td>41/06</td>
<td>Durability of porous asphalt - International experience</td>
<td>Carsten Bredahl Nielsen</td>
</tr>
<tr>
<td>42/06</td>
<td>Porous pavements with PMB – Selection of road sections</td>
<td>Carsten Bredahl Nielsen</td>
</tr>
<tr>
<td>43/06</td>
<td>Notes from INTER-NOISE 2006</td>
<td>Hans Bendtsen</td>
</tr>
<tr>
<td>44/06</td>
<td>Acoustic performance - low noise road pavements</td>
<td>Bent Andersen, Jørgen Kragh, Hans Bendtsen</td>
</tr>
<tr>
<td>45/06</td>
<td>Noise reducing pavements – Evaluation workshop</td>
<td>Carsten B. Nielsen, Hans Bendtsen</td>
</tr>
<tr>
<td>46/06</td>
<td>Traffic noise at two-layer porous asphalt – Øster Søgade, Year No. 7</td>
<td>Jørgen Kragh</td>
</tr>
<tr>
<td>47/07</td>
<td>Microstructure of porous pavements – experimental procedures</td>
<td>Carsten B. Nielsen</td>
</tr>
<tr>
<td>48/07</td>
<td>Ravelling of porous pavements – assessments of test sections</td>
<td>Carsten B. Nielsen</td>
</tr>
<tr>
<td>49/07</td>
<td>Railway crossings - Road traffic noise measurements</td>
<td>Sigurd N. Thomsen, Jørgen Kragh, Hans Bendtsen</td>
</tr>
<tr>
<td>50/07</td>
<td>Roads with paving Stones - Noise measurements</td>
<td>Sigurd N. Thomsen, Jørgen Kragh, Hans Bendtsen</td>
</tr>
<tr>
<td>51/07</td>
<td>Trafikstøj ved rumleniller – et pilotforsag</td>
<td>Jørgen Kragh, Bent Andersen</td>
</tr>
<tr>
<td>52/07</td>
<td>Traffic Safety and Noise Reduction - Thin Layers</td>
<td>Hans Bendtsen, Jørn Raaberg</td>
</tr>
<tr>
<td>53/07</td>
<td>Modified bitumen in porous pavements – Assessment of test sections</td>
<td>Carsten B. Nielsen</td>
</tr>
<tr>
<td>54/07</td>
<td>Clogging of Porous Pavements - Assessment of test sections</td>
<td>Carsten B. Nielsen</td>
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<tr>
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<td>Clogging of Porous Pavements - International Experiences</td>
<td>Hans Bendtsen, Jørn Raaberg</td>
</tr>
</tbody>
</table>